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See application file for complete search history.

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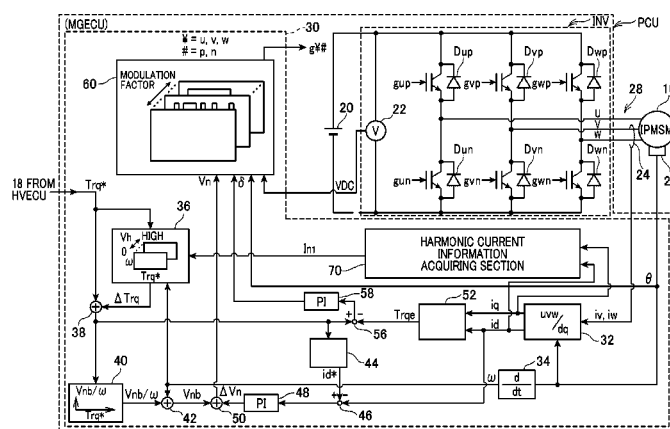
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(57) **ABSTRACT**

A control device for a rotating electrical machine is provided that is capable of suppressing reduction in controllability of torque attributed to harmonic currents. According to the exemplary embodiment of the present invention, a designated torque value  $\text{Trq}^*$  designated by a hybrid vehicle electronic control unit (HVECU) is corrected by a compensation amount  $\Delta\text{Trq}$  calculated using a harmonic voltage  $V_h$ , the designated torque value  $\text{Trq}^*$ , and an electric angular velocity  $\omega$  as inputs. An operating signal generating section generates an operating signal  $g_{\text{y\#}}$  using a designated norm value  $V_n$  set based on the corrected torque designated value  $\text{Trq}^*$  and a phase  $\delta$  serving as a manipulated variable for performing feedback control of an estimated torque to the designated torque value  $\text{Trq}^*$ , and outputs the generated operating signal  $g_{\text{y\#}}$  to a power supply circuit of a motor generator.

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**18 Claims, 8 Drawing Sheets**



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FIG. 1

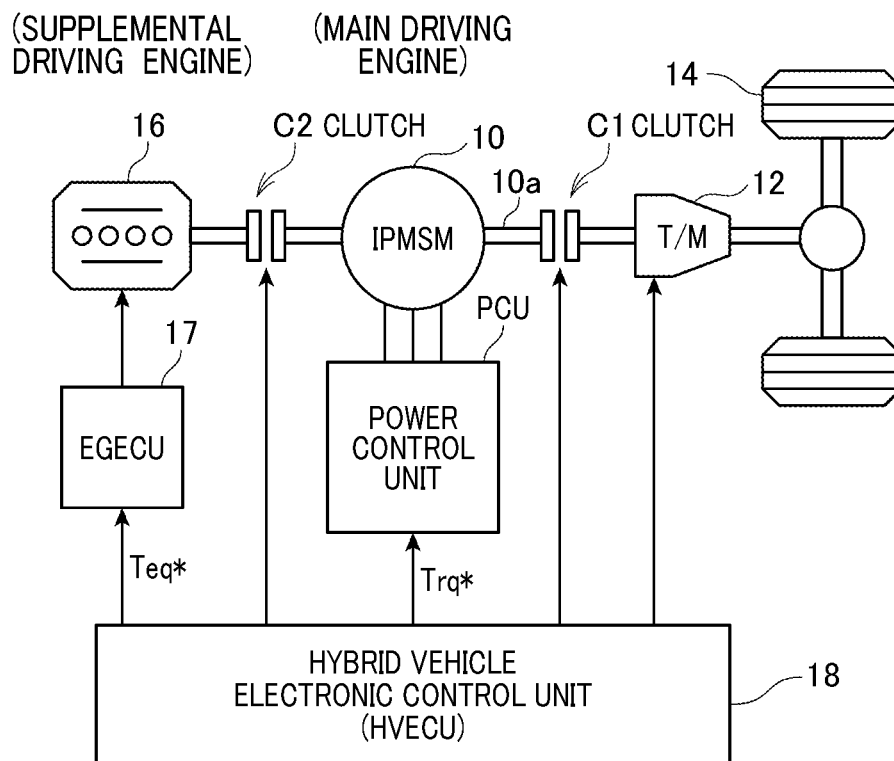
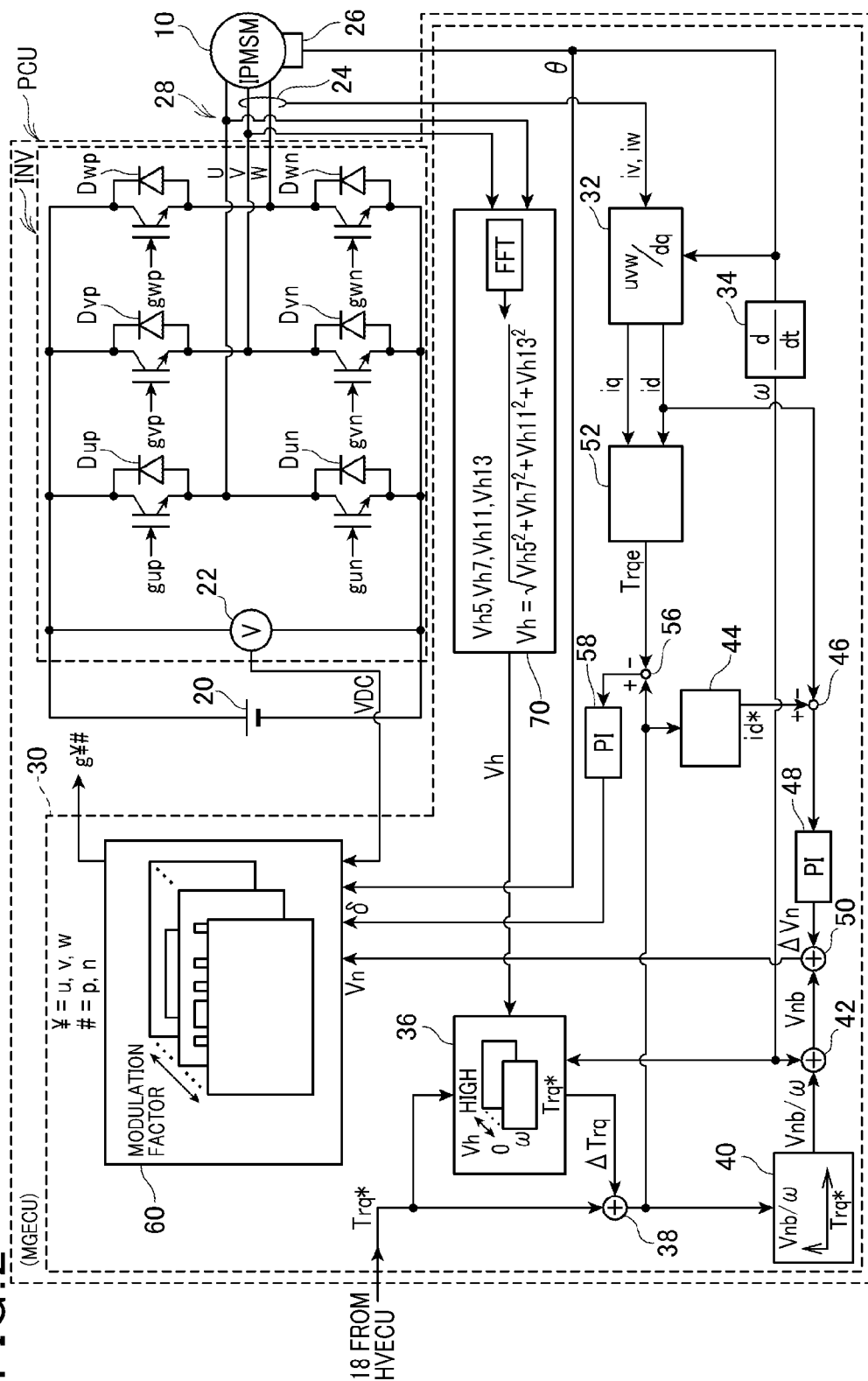


FIG. 2



**FIG. 3**

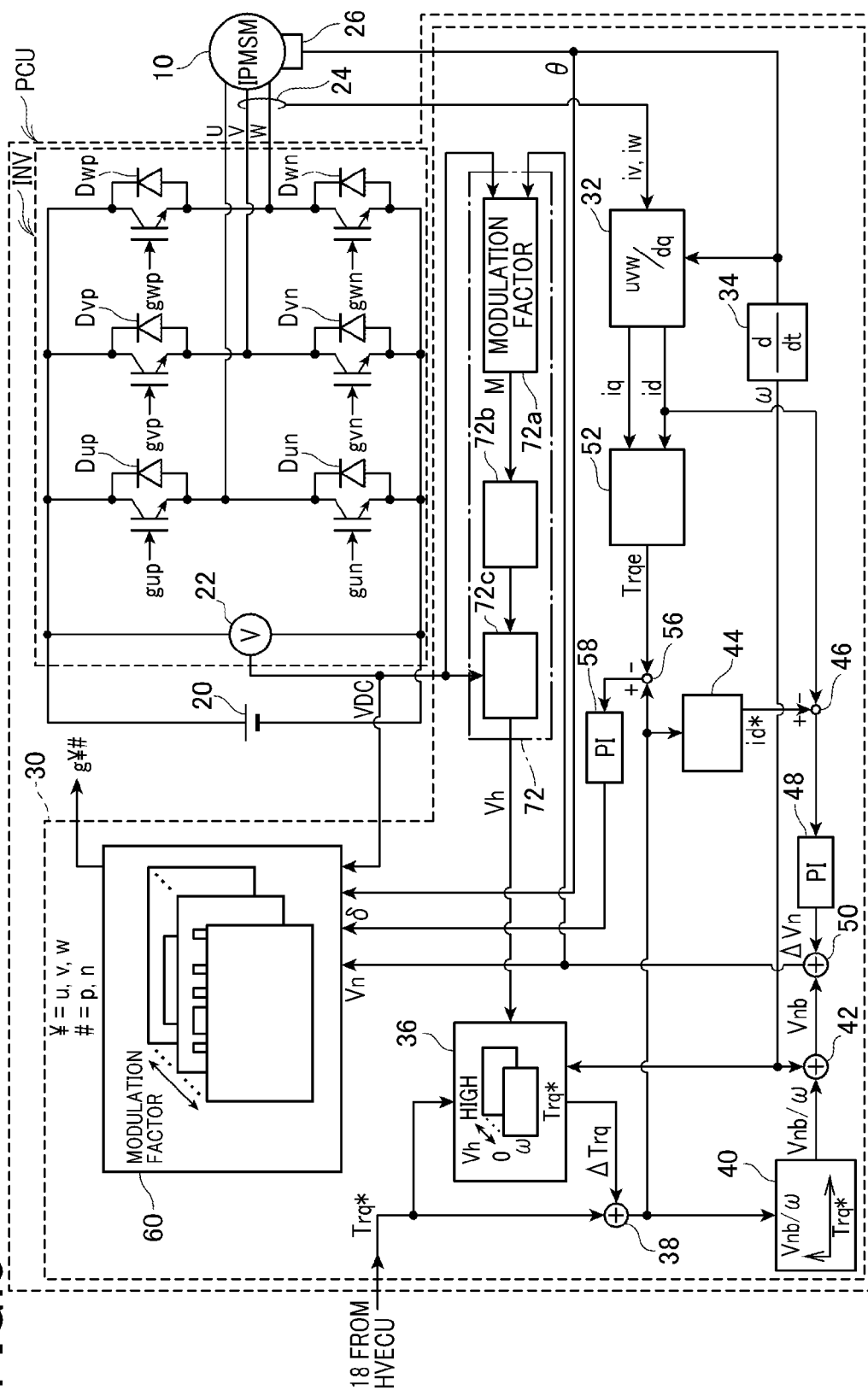


FIG. 4

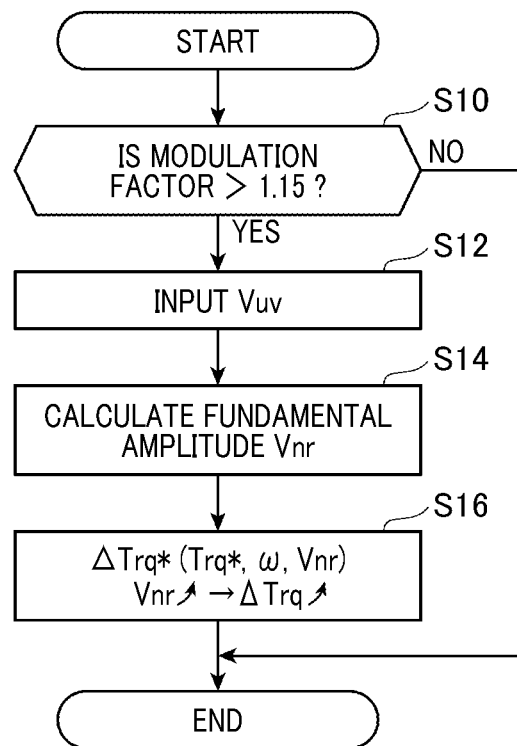


FIG. 5

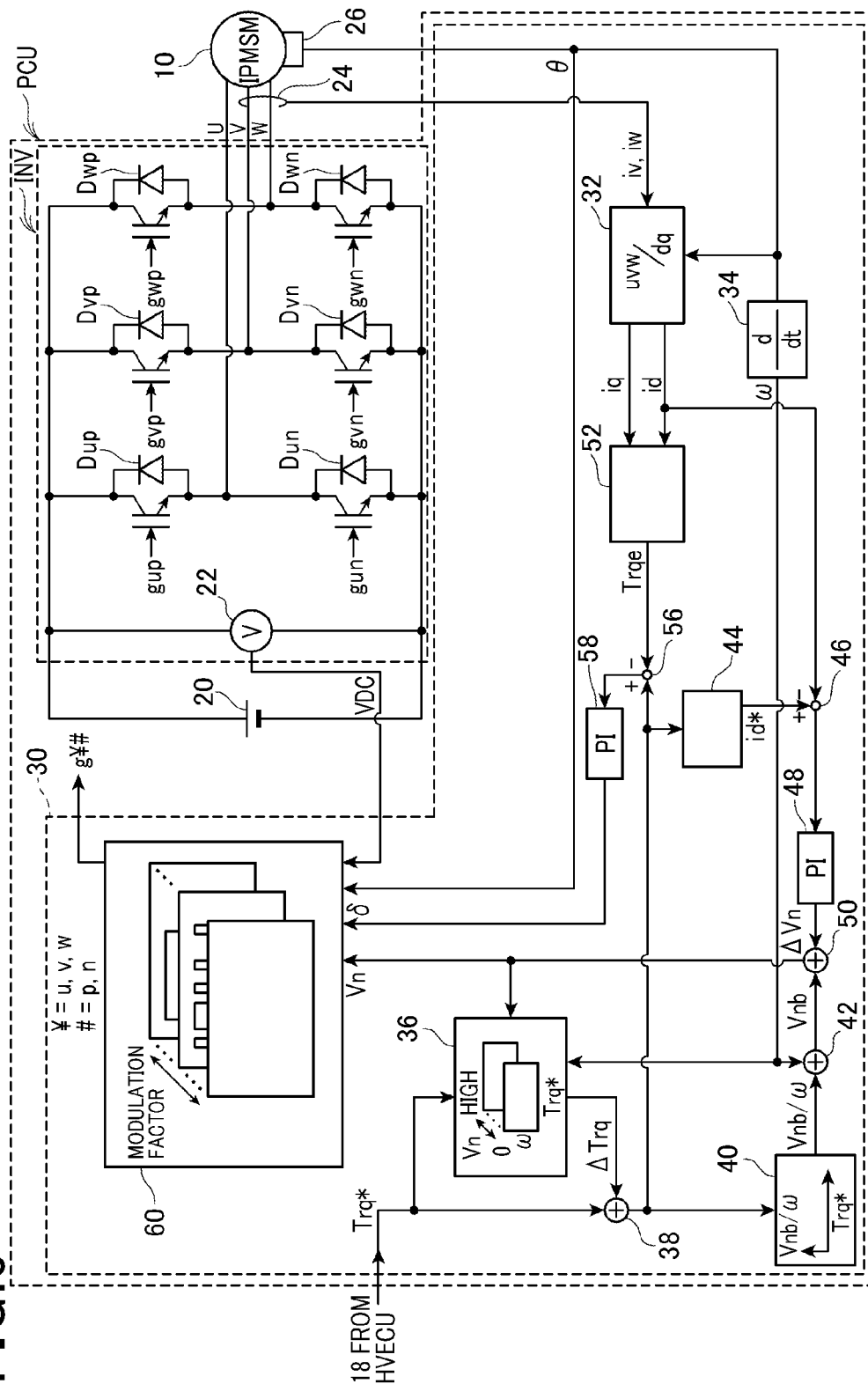


FIG. 6

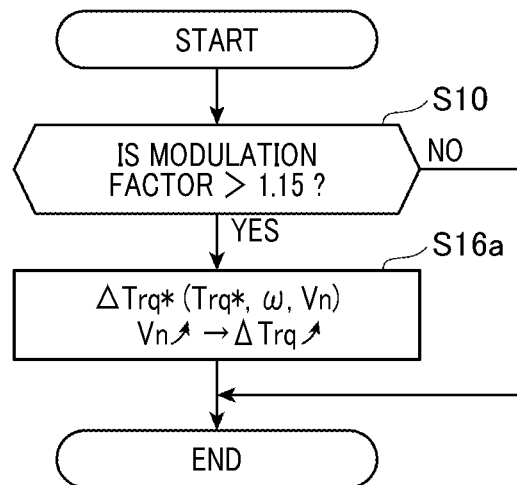


FIG. 7

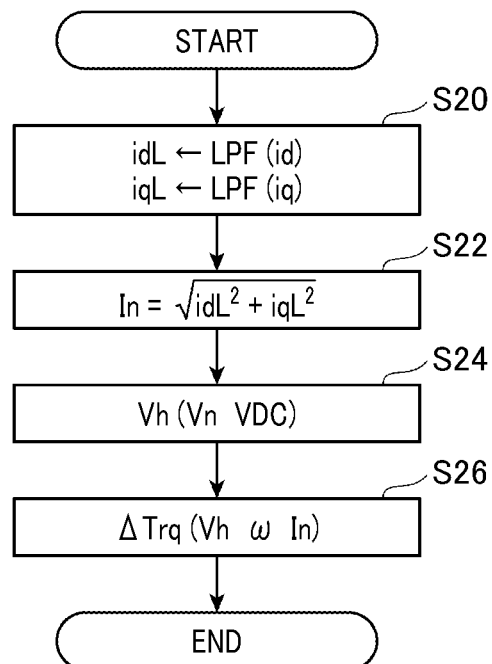
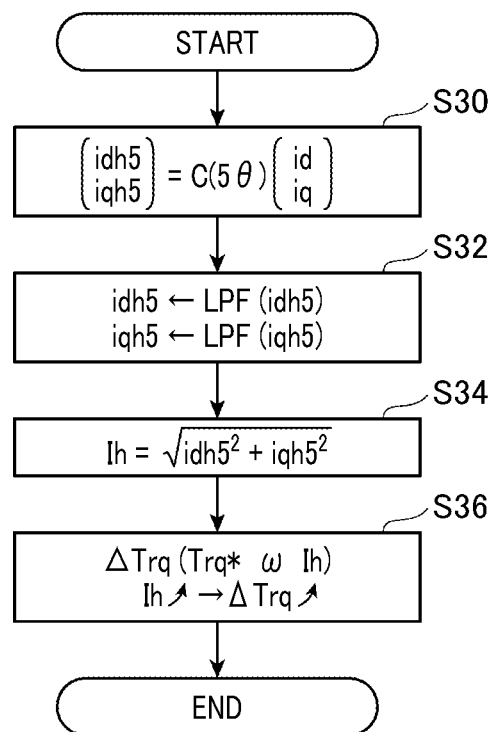
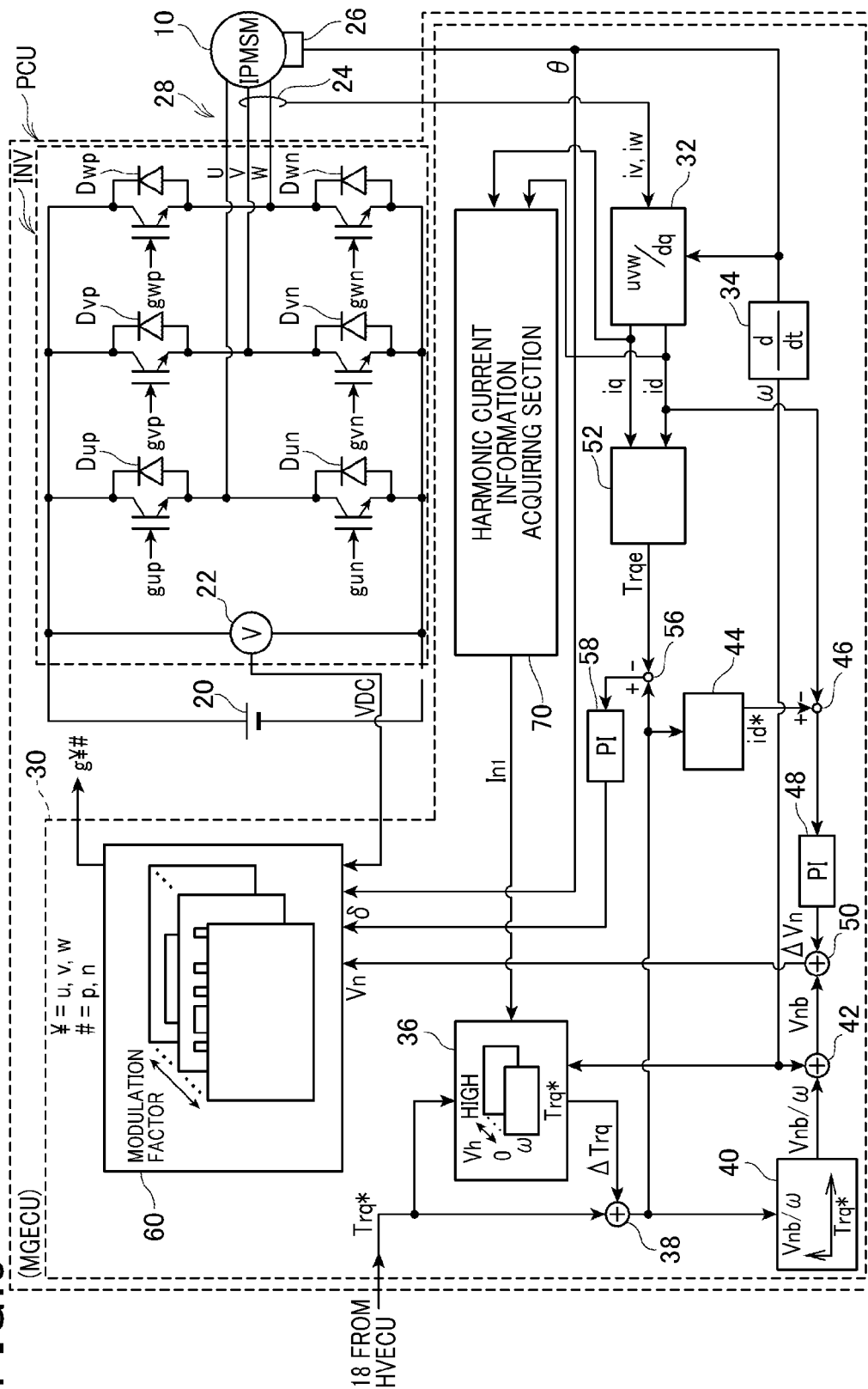




FIG. 8



**FIG. 9**



# CONTROL DEVICE FOR ROTATING ELECTRICAL MACHINE

## CROSS-REFERENCE TO RELATED APPLICATION

This application is based on and claims the benefit of priorities from earlier Japanese Patent Application No. 2012-146372 filed Jun. 29, 2012 the description of which is incorporated herein by reference.

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The present invention relates to a control device for a rotating electrical machine that controls the torque of the rotating electrical machine by converting direct-current voltage to alternating-current voltage and applying the alternating-current voltage to the rotating electrical machine.

### 2. Description of the Related Art

As this type of device, for example, JP-B-4839119 proposes correction of a designated torque value based on an electric angular velocity and the input voltage of an inverter when the output voltage of the inverter is manipulated, to perform feedback control of a current flowing through a motor to a current based on the designated torque value. This technique is proposed in light of the actual torque of the motor not necessarily becoming the designated torque value depending on the feedback control to the current based on the designated torque value.

In the overmodulation range of the rotating electrical machine, the effects of harmonic currents become significant due to increase in harmonic components included in the output voltage of the inverter. The inventors have discovered that, depending on the specification of the motor and the like, reduction in the controllability of torque may become significant due to harmonic currents.

Therefore, a control device for a rotating electrical machine is desired that is capable of suppressing reduction in the controllability of torque due to harmonic currents.

## SUMMARY

As an exemplary embodiment, the present application provides a control device of a rotating electrical machine including: a harmonic current information acquiring section that acquires information related to harmonic currents flowing to the rotating electrical machine; a manipulated variable calculating section that uses the acquired information related to harmonic currents as input, and calculates a manipulated variable to control torque serving as a controlled variable of the rotating electrical machine to a designated torque value; and an operating section that operates an alternating-current voltage applying device that applies an alternating-current voltage to the rotating electrical machine, based on the manipulated variable calculated by the manipulated variable calculating section.

According to the configuration, a manipulated variable capable of compensating loss attributed to harmonic currents can be calculated through use of the information related to harmonic currents. Moreover, control accuracy of the designated torque value can be improved.

Expansion of the concept related to the following exemplary embodiments of the present invention is described under "Other Embodiments" following the description of the exemplary embodiments.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of a system configuration according to a first embodiment;

FIG. 2 is a block diagram of processes related to torque control according to the first embodiment;

FIG. 3 is a block diagram of processes related to torque control according to a second embodiment;

FIG. 4 is a flowchart of procedures in a process for calculating a compensation amount according to a third embodiment;

FIG. 5 is a block diagram of processes related to torque control according to a fourth embodiment;

FIG. 6 is a flowchart of procedures in a process for calculating a compensation amount according to the fourth embodiment;

FIG. 7 is a flowchart of procedures in a process for calculating a compensation amount according to a fifth embodiment;

FIG. 8 is a flowchart of procedures in a process for calculating a compensation amount according to a sixth embodiment; and

FIG. 9 is a block diagram of processes related to torque control according to the sixth embodiment.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

### First Embodiment

A first embodiment will hereinafter be described with reference to the drawings. According to the first embodiment, an example is given in which the present invention is applied to a control device for a rotating electrical machine (motor generator) serving as a main driving engine mounted in a hybrid car.

FIG. 1 is a diagram of a system configuration according to the first embodiment.

As shown in FIG. 1, a motor generator 10 that is a rotating electrical motor is a three-phase electric motor/power generator serving as the main driving engine of a hybrid car. The motor generator 10 is mechanically connected to a driving wheel 14. In other words, a rotating shaft 10a of the motor generator 10 is mechanically connected to the driving wheel 14 with an electronically controlled clutch C1 and a transmission 12 therebetween. According to the first embodiment, the motor generator 10 is assumed to be an interior permanent magnet synchronous motor (IPMSM).

The rotating shaft 10a of the motor generator 10 is further mechanically connected to an internal combustion engine (gasoline engine 16) serving as a supplemental driving engine, with an electronically controlled clutch C2 therebetween.

A hybrid vehicle electronic control unit (HVECU 18) operates the motor generator 10, the gasoline engine 16, and the transmission 12 such as to control the controlled variables thereof. Specifically, the HVECU 18 divides the requested torque of the driving wheel 14 into a designated torque value  $Trq^*$  of the motor generator 10 and a designated torque value  $Teg^*$  of the gasoline engine 16. The HVECU 18 then outputs the designated torque value  $Trq^*$  to a power control unit PCU and the designated torque value  $Teg^*$  to a gasoline engine electronic control unit (EGECU 17). As a result, the power control unit PCU controls the torque of the motor generator 10 to the designated torque value  $Trq^*$ . The EGECU 17 controls the torque of the gasoline engine 16 to the designated

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torque value  $T_{eq}^*$ . In addition, the HVECU 18 performs engaging and releasing operations of the clutches C1 and C2.

FIG. 2 is a block diagram of processes related to torque control according to the first embodiment. FIG. 2 shows the motor generator 10 and the power control unit PCU. As shown in FIG. 2, the motor generator 10 is connected to a high voltage battery 20 via an inverter INV within the power control unit PCU. The inverter INV includes three sets of serially connected members composed of switching elements  $S_{Yp}$  and  $S_{Yn}$  ( $Y=u, v, w$ ). The respective connection points of the serially connected members are respectively connected to the U-phase, the V-phase, and the W-phase of the motor generator 10. According to the first embodiment, insulated gate bipolar transistors (IGBT) are used as the switching elements  $S_{Y\#}$  ( $Y=u, v, w; \# = n, p$ ). A diode  $D_{Y\#}$  is connected in reverse parallel to each switching element  $Y\#$ .

According to the first embodiment, the following is included as a detecting means for detecting the state of the motor generator 10 and the inverter INV. First, a voltage sensor 22 that detects the input voltage (power supply voltage VDC) of the inverter INV is included. In addition, a current sensor 24 that detects currents  $i_v$  and  $i_w$  that flow through the V-phase and the W-phase of the motor generator 10 is included. Furthermore, a rotation angle sensor 26 that detects the rotation angle (electrical angle  $\theta$ ) of the motor generator 10 is included.

The detection values of the various sensors are loaded into a motor generator electronic control unit (MGECU30) via an interface. The MGECU 30 generates and outputs operating signals for operating the inverter INV based on the detection values of the various sensors. Here, the signals for operating the switching elements  $S_{Y\#}$  of the inverter INV are operating signals  $g_{Y\#}$ .

The MGECU 30 operates the inverter INV such as to control the torque of the motor generator 10 to the above-described designated torque value  $Trq^*$ . Regarding this operation, "Overview of processes related to control of the motor generator 10" will first be described hereafter, followed by a description of "Process for correcting the designated torque value  $Trq^*$ ".

[Overview of Processes Related to Control of the Motor Generator 10]

A two-phase converter 32 converts the currents  $i_v$  and  $i_w$  detected by the current sensor 24 to a d-axis actual current  $i_d$  and a q-axis actual current  $i_q$  that are currents of the rotating frame. On the other hand, a velocity calculating section 34 calculates an electric angular velocity  $\omega$  based on the electric angle  $\theta$  detected by the rotation angle sensor 26.

A correcting section 38 within the MGECU 30 corrects the designated torque value  $Trq^*$  by adding a compensation amount  $\Delta Trq$  calculated by a compensation amount calculating means (compensation amount calculating section 36) to the designated torque value  $Trq^*$ . The output of the correcting section 38 becomes the input of a norm setting section 40.

The norm setting section 40 uses the designated torque value  $Trq^*$  outputted by the correcting section 38 as input, and sets a designated velocity normalizing norm value  $V_{nb}/\omega$  that is obtained by a base value  $V_{nb}$  of a norm of an output voltage vector of the inverter INV being divided by the electric angular velocity  $\omega$ . Here, among the norms capable of generating the designated torque value  $Trq^*$ , the norm base value  $V_{nb}$  is used to perform minimum-current maximum-torque control. A velocity multiplying section 42 calculates the norm base value  $V_{nb}$  by multiplying the designated velocity normalizing norm value  $V_{nb}/\omega$  by the electric angular velocity  $\omega$ .

On the other hand, a designated current setting section 44 sets a designated value (designated current  $i_d^*$ ) of the d-axis

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current for actualizing the designated torque value  $Trq^*$ . Here, the designated current  $i_d^*$  is the current value on the d-axis required when the designated torque value  $Trq^*$  is actualized by minimum-current maximum-torque control. This is to achieve consistency with the setting made by the norm setting section 40.

A deviation calculating section 46 subtracts the actual current  $i_d$  from the designated current  $i_d^*$  and inputs the result into a correction amount calculating section 48. The correction amount calculating section 48 uses the output signal from the deviation calculating section 46 as input, and calculates a correction amount  $\Delta V_n$  of the norm base value  $V_{nb}$  as a manipulated variable for performing feedback control of the actual current  $i_d$  to the designated current  $i_d^*$ . The correction amount  $\Delta V_n$  can be calculated as a sum of the respective outputs of a proportional element and an integrated element of which the above-described deviation is the input. The actual current  $i_d$  serving as the input of the deviation calculating section 46 has preferably undergone a low-pass filtering process for removing higher harmonic components.

A correcting section 50 calculates the designated final norm value  $V_n$  by adding the correction amount  $\Delta V_n$  to the norm base value  $V_{nb}$ .

On the other hand, a torque estimator 52 uses the actual currents  $i_d$  and  $i_q$  as inputs, and calculates an estimated torque  $Trqe$  of the motor generator 10. The process may be performed by calculation using a map storing the relationship between the actual currents  $i_d$  and  $i_q$  and torque, or using a model formula. A deviation calculating section 56 subtracts the estimated torque  $Trqe$  from the designated torque value  $Trq^*$  outputted by the correcting section 38 and inputs the result into a phase setting section 58. The phase setting section 58 sets a phase  $\delta$  as a manipulated variable for performing feedback control of the estimated torque  $Trqe$  to the designated torque value  $Trq^*$ . Specifically, the phase  $\delta$  is calculated as a sum of the respective outputs of the proportional element and the integrated element of which the output signal of the deviation calculating section 56 is the input.

Then, an operating signal generating section 60 generates and outputs an operating signal  $g_{Y\#}$  based on the phase  $\delta$  set by the phase setting section 58, the designated norm value  $V_n$  outputted by the correcting section 50, the power supply voltage VDC, and the electric angle  $\theta$ . Specifically, the operating signal generating section 60 stores an operating signal waveform amounting to a single rotation cycle of the electric angle for each modulation factor as map data. The operating signal generating section 60 calculates the modulation factor based on the power supply voltage VDC and the designated norm value  $V_n$  and selects the corresponding operating signal waveform based on the calculated modulation factor. Here, the upper limit of the modulation factor is "1.27" that is the modulation factor during rectangular wave control. Therefore, when the modulation factor is the maximum value "1.27", as the operating signal waveform, a waveform (single pulse waveform) is selected in which a period in which the switching element  $S_{Yp}$  on the high potential side is set to ON and a period in which the switching element  $S_{Yn}$  on the low potential side is set to ON each occur once during a single rotation cycle of the electric angle. This waveform is the waveform during rectangular wave control.

After selecting the operating signal waveform in this way, the operating signal generating section 60 generates the operating signal by setting the output timing of the waveform based on the phase  $\delta$  set by the phase setting section 58. When the modulation factor is the maximum value "1.27" and rect-

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angular wave control is performed, field-weakening control is performed by manipulation of the phase  $\delta$  by the phase setting section 58.

[Process for Correcting the Designated Torque Value  $Trq^*$ ]

As described above, should the pulse pattern of the inverter INV be decided based on the designated norm value  $V_n$  and the power supply voltage VDC that are determined based on the designated torque value  $Trq^*$ , and the phase  $\delta$  be manipulated by the manipulated variable for performing torque feedback control, the torque of the motor generator 10 can basically be controlled to the designated torque value  $Trq^*$ . However, when the manipulated variable of the inverter INV is determined based on the designated torque value  $Trq^*$  inputted into the MGECU 30, the actual torque of the motor generator 10 may be smaller than the designated torque value  $Trq^*$ . This is because not all current flowing through the motor generator 10 contributes to generation of torque. Therefore, according to the first embodiment, a process is performed to compensate for the amount of loss of the current not contributing to the generation of torque.

Here, factors causing loss include mechanical loss and core loss. Core loss is largely classified into hysteresis loss and eddy current loss. Here, hysteresis loss includes that attributed to harmonic currents, in addition to that attributed to fundamental current. According to the first embodiment, increase in hysteresis loss caused by harmonic currents is a particular concern. Therefore, compensation for only hysteresis loss attributed to the fundamental current is insufficient for the actual amount of loss. Here, according to the first embodiment, hysteresis loss attributed to harmonic currents is also compensated based on information on the harmonic components of the output voltage of the inverter INV.

Specifically, a harmonic voltage calculating section 70 uses a detection value of a line-to-line voltage sensor 28 as input, and calculates a harmonic voltage  $V_h$  based on the detection value. The line-to-line voltage sensor 28 detects the voltage (output line-to-line voltage) between the output terminals of the U-phase and the V-phase of the inverter INV. More specifically, the harmonic voltage calculating section 70 extracts harmonic components of certain orders by performing a fast Fourier transform (FFT) analysis of the detection value, and calculates the root-mean-square value of the components as the harmonic voltage  $V_h$ . Here, according to the first embodiment, the 5th order, the 7th order, the 11th order, and the 13th order are used as certain orders. This is because hysteresis loss attributed to harmonics of these orders tends to become significant. According to the first embodiment, the harmonic voltage calculating section 70 configures a "harmonic voltage substituting means" of the claims.

The compensation amount calculating section 36 uses the designated torque value  $Trq^*$ , the electric angular velocity  $\omega$ , and the harmonic voltage  $V_h$  as inputs, and calculates the compensation amount  $\Delta Trq$  to compensate for hysteresis loss. Here, a three-dimensional map prescribing the relationship between the harmonic voltage  $V_h$ , the designated torque value  $Trq^*$ , and the electric angular velocity  $\omega$ , and the compensation amount  $\Delta Trq^*$  is used.

The three-dimensional map includes the relationship in an instance in which the harmonic voltage  $V_h$  is zero. When the harmonic voltage  $V_h$  is zero, the three-dimensional map prescribes the compensation amount  $\Delta Trq$  for compensating core loss attributed to the fundamental current such as hysteresis loss attributed to the fundamental current, and mechanical loss. On the other hand, when the harmonic voltage  $V_h$  is not zero, the three-dimensional map sets the compensation amount  $\Delta Trq$  for compensating loss attributed to harmonic currents such as hysteresis loss attributed to har-

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monic currents, in addition to the above. Here, the compensation amount itself for compensating hysteresis loss attributed to harmonic currents is determined by the harmonic voltage and the electric angular velocity  $\omega$ . Here, the electric angular velocity  $\omega$  is a parameter used so that hysteresis loss is dependent on frequency. Hysteresis loss attributed to harmonic currents increases as the harmonic currents increase. The harmonic currents increase as the harmonic voltage increases. Therefore, the compensation amount for hysteresis loss attributed to the harmonic voltage  $V_h$  increases as the harmonic voltage  $V_h$  increases.

Effects according to the first embodiment are as follows.

- (1) Hysteresis loss attributed to harmonic currents can be favorably compensated by using the harmonic voltage  $V_h$ .
- (2) The harmonic voltage  $V_h$  can be calculated with high accuracy by using the detection value of the output line-to-line voltage of the inverter INV as input and calculating the harmonic voltage  $V_h$ .
- (3) The output voltage (designated norm value  $V_n$ ) of the inverter INV is the feedback manipulated variable (amount to be corrected by the correction amount calculating section 48). In this instance, an unambiguous relationship is not established between the output voltage of the inverter INV and an operating point determined by torque and electric angular velocity. In particular, during transient operation when the designated value (designated torque value  $Trq^*$ ) of the controlled variable of the motor generator 10 and the input voltage (power supply voltage VDC) of the inverter INV change, the output voltage of the inverter INV differs from that during steady operation. Therefore, hysteresis loss attributed to harmonic currents can be compensated with higher accuracy by referencing the output voltage of the inverter INV during calculation of the compensation amount  $\Delta Trq$ , compared to when the compensation amount is calculated for each operating point without referencing the output voltage of the inverter INV.
- (4) The compensation amount  $\Delta Trq$  for the designated torque value  $Trq^*$  is calculated in a system in which the requested output of the driving wheel 14 is assigned to the motor generator 10 and the gasoline engine 16. In a system such as this, because high accuracy is required for the torque requested of the motor generator 10, the benefit of using the process for calculating the compensation amount  $\Delta Trq$  is particularly great.

## Second Embodiment

A second embodiment will hereinafter be described with reference to the drawings, mainly focusing on the differences with the above-described first embodiment. FIG. 3 shows a system configuration according to the second embodiment. Components and processes in FIG. 3 corresponding with those shown in FIG. 2 are given the same reference numbers for convenience. Descriptions thereof are omitted or simplified. This similarly applies to third and subsequent embodiments described hereafter.

As shown in FIG. 3, according to the second embodiment, a harmonic voltage calculating section 72 uses the designated norm value  $V_n$  and the power supply voltage VDC as inputs, and calculates the harmonic voltage  $V_h$ . In other words, the harmonic voltage calculating section 72 uses the designated norm value  $V_n$  and the power supply voltage VDC as inputs and calculates a modulation factor  $M$  in a modulation factor calculating section 72a. Here, the modulation factor  $M$  is a parameter for determining the harmonic component of output

line-to-line voltage of the inverter INV. In other words, when the modulation factor M is low (such as "1.15" or lower), the output line-to-line voltage of the inverter INV can be that simulating the fundamental. In other words, when average values of the voltage of the output terminals of the inverter INV are successively plotted during a single ON/OFF cycle of the switching elements S<sub>yp</sub> and S<sub>yn</sub>, the output line-to-line voltage determined by the plotted points can be considered as the fundamental (sine wave of the electric angle cycle). Therefore, when the modulation factor M is low, the harmonic voltage can be ignored. On the other hand, when the modulation factor M is high, the harmonic voltage becomes significant because the output line-to-line voltage of the inverter INV cannot be that simulating the fundamental.

The modulation factor M is outputted to a harmonic component calculating section 72b. Here, a harmonic component normalized by the power supply voltage VDC is calculated. This is performed in light of the absolute value of the harmonic voltage not being determined solely by the modulation factor M because the size of the actual harmonic voltage depends on the power supply voltage VDC. Then, a power supply referencing section 72c calculates the harmonic voltage V<sub>h</sub> based on the normalized harmonic component calculated by the harmonic component calculating section 72b and the power supply voltage VDC.

According to the second embodiment, in addition to the above-described effects (1), (3), and (4) according to the first embodiment, the following effects can be achieved.

- (5) The harmonic component of the actual output voltage of the inverter INV can be calculated with high accuracy by calculating the harmonic voltage V<sub>h</sub> using the designated value (designated norm value V<sub>n</sub>) related to the fundamental amplitude of the output line-to-line voltage of the inverter INV and the power supply voltage VDC.

#### Third Embodiment

A third embodiment will hereinafter be described with reference to the drawings, mainly focusing on the differences with the above-described first embodiment.

FIG. 4 shows the processing operations during an overmodulation process in particular, within the process for calculating the compensation amount  $\Delta\text{Trq}$  according to the third embodiment. The process is repeatedly performed by the MGECU 30 at, for example, a predetermined cycle.

In the series of processing operations, first, at Step 10, the MGECU 30 judges whether or not the modulation factor M is greater than 1.15. The MGECU 30 performs the processing operation to judge whether or not an overmodulation process is being performed. Here, the motor generator 10 is determined to be in the overmodulation range when the modulation factor M is greater than 1.15 in light of the setting of the operating signal by the operating signal generating section 60 according to the third embodiment. In other words, according to the third embodiment, it is assumed that the operating signal is set such that the output line-to-line voltage of the inverter INV is that which simulates the fundamental until the fundamental amplitude of the output line-to-line voltage of the inverter INV becomes the power supply voltage VDC.

When judged that the overmodulation process is being performed, at Step 12, the MGECU 30 inputs a detection value V<sub>uv</sub> of the line-to-line voltage detected by the line-to-line voltage sensor 28 shown in FIG. 2. At subsequent Step 14, the MGECU 30 calculates a fundamental amplitude V<sub>nr</sub> of the detection value V<sub>uv</sub>. This processing operation can be performed by FFT analysis or the like. In addition, for example, the detection value V<sub>uv</sub> may be treated as the aver-

age value of the norms of the vectors that the coordinate is converted to a coordinate system which rotates at the electric angular velocity  $\omega$ .

Then, at Step 16, the MGECU 30 uses the fundamental amplitude V<sub>nr</sub>, the designated torque value Trq\*, and the electric angular velocity  $\omega$  as inputs, and calculates the compensation amount  $\Delta\text{Trq}$ . Here, when the designated torque value Trq\* and the electric angular velocity  $\omega$  are the same, the compensation amount  $\Delta\text{Trq}$  becomes a greater value, the greater the fundamental amplitude V<sub>nr</sub> is. This is in light of the harmonic voltage becoming greater, the greater the fundamental amplitude V<sub>nr</sub> is, even when the modulation factor is the same. In particular, when field-weakening control is performed, because the modulation factor is constant, the compensation amount  $\Delta\text{Trq}$  can be calculated with high accuracy by increasing the compensation amount  $\Delta\text{Trq}$  depending on the fundamental amplitude V<sub>nr</sub>.

As shown in FIG. 2, an open-loop manipulated variable (norm base value V<sub>nb</sub>) of the fundamental amplitude of the output line-to-line voltage of the inverter INV is corrected by the correction amount  $\Delta\text{Vn}$  of the correction amount calculating section 48. Therefore, the norm base value V<sub>nb</sub> determined by the designated torque value Trq\* and the electric angular velocity  $\omega$  does not necessarily match the fundamental amplitude V<sub>nr</sub>. Therefore, when the fundamental amplitude V<sub>nr</sub> is used, the compensation amount  $\Delta\text{Trq}$  can be set to a more suitable value for compensating for loss, compared to when the fundamental amplitude V<sub>nr</sub> is not used.

#### Fourth Embodiment

A fourth embodiment will hereinafter be described with reference to the drawings, mainly focusing on the differences with the above-described third embodiment.

FIG. 5 shows a system configuration according to the fourth embodiment. Components and processes in FIG. 5 corresponding to those shown in FIG. 1 are given the same reference numbers for convenience.

In FIG. 5, processes in the overmodulation range are shown as the processes within the MGECU 30. In the overmodulation range, according to the fourth embodiment, the compensation amount calculating section 36 uses the designated norm value V<sub>n</sub>, the designated torque value Trq\*, and the electric angular velocity  $\omega$  as inputs, and calculates the compensation amount  $\Delta\text{Trq}$ .

FIG. 6 shows the processing operations during the overmodulation process in particular, within the process for calculating the compensation amount  $\Delta\text{Trq}$  according to the fourth embodiment. The process is repeatedly performed by the MGECU 30 at, for example, a predetermined cycle. Processing operations in FIG. 6 that correspond with those in FIG. 4 are given the same step numbers for convenience.

In the series of processing operations, when judged YES at Step 10, at Step 16a, the MGECU 30 uses the designated norm value V<sub>n</sub> in addition to the designated torque value Trq\* and the electric angle velocity  $\omega$  as inputs, and calculates the compensation amount  $\Delta\text{Trq}$ . Here, for the same purpose as at Step 16 in FIG. 4, the compensation value  $\Delta\text{Trq}$  is set to a greater value, the greater the designated norm value V<sub>n</sub> is.

#### Fifth Embodiment

A fifth embodiment will hereinafter be described with reference to the drawings, mainly focusing on the differences with the above-described first embodiment.

FIG. 7 shows the process for calculating the compensation amount  $\Delta Trq$  according to the fifth embodiment. The process is repeatedly performed by the MGECU 30 at, for example, a predetermined cycle.

In the series of processing operations, first, at Step 20, the MGECU 30 calculates average currents  $idL$  and  $iqL$  by performing a low-pass filtering process on the actual currents  $id$  and  $iq$ . At subsequent Step 22, the MGECU 30 calculates the vector norm (current amplitude  $I_n$ ) of the average currents  $idL$  and  $iqL$ . Furthermore, at Step 24, the MGECU 30 calculates the harmonic voltage  $V_h$  in the manner according to the second embodiment, based on the power supply voltage  $VDC$  and the designated norm value  $V_n$ . Then, at Step 26, the MGECU 30 uses the harmonic voltage  $V_h$ , the electric angular velocity  $\omega$ , and the current amplitude  $I_n$  as inputs, and calculates the compensation amount  $\Delta Trq$ . Here, when the harmonic voltage  $V_h$  is zero, the MGECU 30 calculates the compensation amount for compensating hysteresis loss and the like attributed to the fundamental current based on the electric angular velocity  $\omega$  and the current amplitude  $I_n$ .

#### Sixth Embodiment

A sixth embodiment will hereinafter be described with reference to the drawings, mainly focusing on the differences with the above-described first embodiment.

FIG. 8 shows the process for calculating the compensation amount  $\Delta Trq$  according to the sixth embodiment. The process is repeatedly performed by the MGECU 30 at, for example, a predetermined cycle.

In the series of processing operations, first, at Step 30, the MGECU 30 calculates 5th order harmonic currents  $idh5$  and  $iqh5$  by converting the actual currents  $id$  and  $iq$  to components of a coordinate system that rotates at a speed of  $5\omega$ . Next, at Step 32, the MGECU 30 performs a low-pass filtering process on the 5th order harmonic currents  $idh5$  and  $iqh5$ . This is in light of the components determined by the processing operation at Step 30 including components other than the 5th order components to be processed. The other components are thereby removed. Then, at Step 34, the MGECU 30 calculates the vector norm (harmonic amplitude  $I_h$ ) of the 5th order harmonic currents  $idh5$  and  $iqh5$  to which the low-pass filtering process has been performed. According to the sixth embodiment, the processing operations at Step 30 to Step 34 configure a detection value inputting means.

At subsequent Step 36, the MGECU 30 uses the designated torque value  $Trq^*$ , the electric angular velocity  $\omega$ , and the harmonic amplitude  $I_h$  as inputs, and calculates the compensation amount  $\Delta Trq$ . Here, when the designated torque value  $Trq^*$  and the electric angular velocity  $\omega$  are the same, the compensation amount  $\Delta Trq$  becomes a greater value, the greater the harmonic amplitude  $I_h$  is. A block diagram of processes related to torque control according to the sixth embodiment is shown in FIG. 9. In a harmonic current information acquiring section 70 shown in FIG. 9, a process described in relation to FIG. 8 is performed.

#### Other Embodiments

The first to sixth embodiments may be modified as follows. [Regarding the Harmonic Voltage Substituting Means]

According to the first embodiment (FIG. 2), the harmonic voltage  $V_h$  is quantified as the sum of the harmonic voltage vector norms of the 5th, 7th, 11th, and 13th orders. However, this is not limited thereto. In the overmodulation range, harmonic voltages of odd-numbered orders excluding the multiples of 3 are generated. In light of this, the harmonic voltage

$V_n$  may be the root-mean-square value of the harmonic voltage vector norm of the component of an arbitrary order among the harmonic voltages of odd-numbered orders excluding the multiples of 3.

According to the first embodiment (FIG. 2), the method for calculating the harmonic voltage of the output line-to-line voltage of the inverter INV detected by the voltage sensor 28 is not limited to that using FFT analysis. For example, the method may be that in which a band-pass filtering process is performed on the output line-to-line voltage.

According to the second embodiment (FIG. 3), the harmonic voltage  $V_h$  is calculated based on the modulation factor  $M$  and the power supply voltage  $VDC$ . However, this is not limited thereto. For example, the modulation factor  $M$  and the power supply voltage  $VDC$  may be outputted to the compensation amount calculating section 36. In this instance, the compensation amount calculating section 36 can calculate the compensation amount  $\Delta$  based on the modulation factor  $M$ , the power supply voltage  $VDC$ , the designated torque value  $Trq^*$ , and the electric angular velocity  $\omega$ .

[Regarding the Compensation Amount Calculating Means]

According to the first embodiment (FIG. 2), as information related to harmonic voltage, the power supply voltage  $VDC$  and the designated norm value  $V_n$  may be used as inputs. The compensation amount  $\Delta Trq$  may be calculated from the three parameters: power supply voltage  $VDC$ , designated norm value  $V_n$ , and designated torque value  $Trq^*$ . In this instance as well, an approximate value regarding the electric angular velocity  $\omega$  can be estimated by the designated norm value  $V_n$  and the designated torque value  $Trq^*$ . Therefore, it is thought that the compensation amount  $\Delta Trq$  substantially equivalent to that according to the first embodiment can be calculated in a steady operation state. In addition, the compensation amount  $\Delta Trq$  may be calculated from the three parameters, modulation factor  $M$ , power supply voltage  $VDC$ , and designated torque value  $Trq^*$ . Furthermore, a variation example according to the first embodiment is also described under "Regarding the harmonic voltage substituting means".

According to the third embodiment (FIG. 4) and the fourth embodiment (FIG. 6), the compensation amount  $\Delta Trq$  may be calculated only during field-weakening control.

According to the first embodiment (FIG. 2) and the fifth embodiment (FIG. 7), as the information related to harmonic voltage, the power supply voltage  $VDC$  and the designated norm value  $V_n$  may be used as inputs. The compensation amount  $\Delta Trq$  may be calculated from the three parameters: designated norm value  $V_n$ , power supply voltage  $VDC$ , and electric angular velocity  $\omega$ . In this instance as well, an approximate value regarding torque can be estimated by the designated norm value  $V_n$  and the electric angular velocity  $\omega$ . Therefore, it is thought that the compensation amount  $\Delta Trq$  substantially equivalent to those according to the first and sixth embodiments can be calculated in a steady operation state. In addition, the compensation amount  $\Delta Trq$  may be calculated from the three parameters: modulation factor  $M$ , power supply voltage  $VDC$ , and electric angular velocity  $\omega$ . [Regarding the Detection Value Inputting Means]

According to the sixth embodiment (FIG. 8), the harmonic amplitude  $I_h$  is quantified as the 5th order harmonic current vector norm. However, this is not limited thereto. For example, the harmonic amplitude  $I_h$  may be the 7th order harmonic current vector norm. Moreover, for example, the harmonic amplitude  $I_h$  may be the respective vector norms of the 5th, 7th, 11th, and 13th orders.

Furthermore, the vector norm of the harmonic current obtained by performing a band-pass filtering process on the actual currents  $id$  and  $iq$  may also be calculated.

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[Regarding the Harmonic Current Information Acquiring Section]

The harmonic current information acquiring section is not limited to the harmonic voltage substituting means or the detection value inputting means. For example, the harmonic current information acquiring section may be both the harmonic voltage substituting means and the detection value inputting means. In this instance, the compensation amount calculating means can use a weighted average of the output values of each means as inputs and calculate the compensation amount.

[Regarding the Manipulated Variable Calculating Section]

According to the above-described embodiments, the compensation value  $\Delta Trq$  is added to the designated torque value  $Trq^*$ . However, this is not limited thereto. For example, in FIG. 2, the estimated torque  $Trqe$  serving as an input parameter of the phase setting section 58 may be corrected by being subtracted by the compensation amount  $\Delta Trq$ .

[Regarding the Designated Output Voltage Value]

According to each of the above-described embodiments, the feedback correction amount of the norm base value  $V_{nb}$  is the sum of the respective outputs of the proportional element and the integrated element of which the difference between the actual current  $i_d$  and the designated current  $i_d^*$  is the input. However, this is not limited thereto. For example, the feedback correction amount may be a sum of the respective outputs of the proportional element, the integrated element, and the derivative element.

The means for calculating the feedback compensation amount of the norm base value  $V_{nb}$  is not limited to that performing feedback control of the actual current  $i_d$  to the designated current  $i_d^*$ . For example, the means may be that which performed feedback control of the phases of the designated currents  $i_d^*$  and  $i_q^*$  for achieving the designated torque value  $Trq^*$  to the phases of the actual currents  $i_d$  and  $i_q$ .

The means for calculating the designated output voltage value by feedback control is not limited to that which performs feedback correction of the norm base value  $V_{nb}$ . For example, the means may be that which uses known current feedback control. This sets the designated voltage on the d-q axis as a manipulated variable for performing feedback control of the actual currents  $i_d$  and  $i_q$  to the designated currents  $i_d^*$  and  $i_q^*$ . In this instance, the final designated voltage on the d-q axis is preferably added to feed-forward terms of known non-interactive control, induced voltage compensation, and the like.

Furthermore, the designated output voltage value may be that composed only of the open-loop manipulated variable of the controlled variable.

[Regarding the Rotating Electrical Machine]

The synchronous motor is not limited to the IPMSM, and may be a surface permanent magnet synchronous motor (SPMSM) or a wound-field synchronous motor. In addition, the rotating electrical machine is not limited to the synchronous motor and may be an induction motor.

The subject to be controlled is not limited to the main driving engine of a hybrid car.

[Regarding Other Means for Generating Torque (Supplemental Driving Engine)]

The other means is not limited to the gasoline engine 16 shown in FIG. 1. For example, the other means may be a power generator. Moreover, the other means itself is not required.

[Regarding the Overmodulation Range]

For example, when the operating signal  $g_{Y\#}$  is generated by performing triangular-wave comparison pulse-width modulation (PWM) on the designated voltages of the three phases

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as the manipulated variables for achieving the designated torque value  $Trq^*$ , in a range in which the modulation factor is greater than 1 (one), the output line-to-line voltage of the inverter INV cannot become that simulating the fundamental. Therefore, this range becomes the overmodulation range. Thus, in the range where the modulation factor is greater than 1 (one), the compensation amount  $\Delta Trq$  is calculated such as to compensate hysteresis loss attributed to harmonic currents. (Relationship Between Terms)

A “manipulated variable calculating section” may include the compensation amount calculating section 36, the correcting section 38, the norm setting section 40, the velocity multiplying section 42, the designated current setting section 44, the deviation calculating section 46, the compensation amount calculating section 48, the correcting section 50, the torque estimator 52, the deviation calculating section 56, and the phase setting section 58. In addition, an “operating section” corresponds to the operating signal generating section 60. An “alternating-current voltage applying device” corresponds to the inverter INV.

What is claimed is:

1. A control device for a rotating electrical machine, comprising:

- a harmonic current information acquiring section that acquires information related to harmonic currents flowing to the rotating electrical machine;
- a compensation amount calculating section that calculates a compensation amount for compensating an amount of loss attributed to the harmonic currents and an amount of loss attributed to a fundamental current flowing through the rotating electrical machine by using, as input, the acquired information related to harmonic currents, an electric angular velocity of the rotating electrical machine, and a designated torque value of a controlled variable of the rotating electrical machine or a current amplitude of the rotating electrical machine;
- a correcting section that corrects the designated torque value of the controlled variable by adding the compensation amount to the designated torque value of the controlled variable;
- a manipulated variable calculating section that calculates a manipulated variable to control torque serving as a controlled variable of the rotating electrical machine to the designated torque value of the controlled variable corrected by the correcting section; and
- an operating section that operates an alternating-current voltage applying device that applies an alternating-current voltage to the rotating electrical machine, based on the manipulated variable calculated by the manipulated variable calculating section.

2. The control device for a rotating electrical machine according to claim 1, wherein the compensation amount calculating section calculates the compensation amount in such a manner that the compensation amount is a greater value, the greater the harmonic current is.

3. The control device for a rotating electrical machine according to claim 1, wherein the harmonic current information acquiring section includes a harmonic voltage substituting section that uses an output voltage of the alternating-current voltage applying device as input, and acquires harmonic component information of the output voltage as the information related to harmonic currents.

4. The control device for a rotating electrical machine according to claim 3, wherein the compensation amount calculating section calculates the compensation amount by using, as inputs, the information related to harmonic voltage acquired by the harmonic voltage substituting section and at



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least one of torque of the rotating electrical machine or a current flowing through the rotating electrical machine.

5 The control device for a rotating electrical machine according to claim 3, wherein the compensation amount calculating section calculates the compensation amount by using, as inputs, the information related to harmonic voltage acquired by the harmonic voltage substituting section and an electric angular velocity of the rotating electrical machine.

6 The control device for a rotating electrical machine according to claim 1, wherein the compensation amount calculating section calculates the compensation amount for compensating an amount of loss attributed to the harmonic currents by using, as inputs, the information related to harmonic voltage acquired by the harmonic voltage substituting section, at least one of torque of the rotating electrical machine or a current flowing through the rotating electrical machine, and an electric angular velocity of the rotating electrical machine.

7 The control device for a rotating electrical machine according to claim 6, wherein

the alternating-current voltage applying device is a direct current-to-alternating current converter circuit that selectively connects a terminal of the rotating electrical machine with a positive electrode or a negative electrode of a direct-current voltage source; and

the manipulated variable calculating section performs a process for calculating a manipulated variable based on the information related to harmonic currents in at least an overmodulation range.

8 The control device for a rotating electrical machine according to claim 7, wherein

the rotating electrical machine includes a rotating shaft mechanically connected to another means for generating torque subjected to electronic control; and

the designated torque value serving as input of the manipulated variable calculating section is a torque value assigned to the rotating electrical machine among torque value respectively assigned to the other means and the rotating electrical machine.

9 The control device for a rotating electrical machine according to claim 1, wherein

the alternating-current voltage applying device is a direct current-to-alternating current converter circuit including switching elements that respectively open and close between a terminal of the rotating electrical machine and a positive electrode and a negative electrode of a direct-current voltage source;

the operating section manipulates an output voltage of the direct current-to-alternating current converter circuit as the manipulated variable for controlling the controlled variable of the rotating electrical machine; and

the compensation amount calculating section calculates the compensation amount to be a greater value, the greater a fundamental amplitude of an output line-to-line voltage of the direct current-to-alternating current converter circuit is, in an overmodulation range.

10 The control device for a rotating electrical machine according to claim 1, wherein

the alternating-current voltage applying device is a direct current-to-alternating current converter circuit including switching elements that respectively open and close between a terminal of the rotating electrical machine and a positive electrode and a negative electrode of a direct-current voltage source; and

the output voltage of the alternating-current voltage applying device serving as input of the harmonic voltage

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substituting section is a designated output voltage value of the direct current-to-alternating current converter circuit.

11 The control device for a rotating electrical machine according to claim 10, wherein

the alternating-current voltage applying device is a direct current-to-alternating current converter circuit including switching elements that respectively open and close between a terminal of the rotating electrical machine and a positive electrode and a negative electrode of a direct-current voltage source; and

the harmonic voltage substituting section uses a terminal voltage of the direct-current voltage source, in addition to the output voltage, as input and calculates the information related to harmonic voltage.

12 The control device for a rotating electrical machine according to claim 10, wherein the compensation amount calculating section calculates compensation amount by using, as inputs, the information related to harmonic voltage acquired by the harmonic voltage substituting section, at least one of torque of the rotating electrical machine or a current flowing through the rotating electrical machine, and an electric angular velocity of the rotating electrical machine.

13 The control device for a rotating electrical machine according to claim 12, wherein

the alternating-current voltage applying device is a direct current-to-alternating current converter circuit including switching elements that respectively open and close between a terminal of the rotating electrical machine and a positive electrode and a negative electrode of a direct-current voltage source;

the operating section manipulates an output voltage of the direct current-to-alternating current converter circuit as the manipulated variable for controlling the controlled variable of the rotating electrical machine; and

the compensation amount calculating section calculates the compensation amount to be a greater value, the greater a fundamental amplitude of an output line-to-line voltage of the direct current-to-alternating current converter circuit is, in an overmodulation range.

14 The control device for a rotating electrical machine according to claim 13, wherein

the rotating electrical machine includes a rotating shaft mechanically connected to another means for generating torque subjected to electronic control; and

the designated torque value serving as input of the manipulated variable calculating section is a torque value assigned to the rotating electrical machine among torque value respectively assigned to the other means and the rotating electrical machine.

15 The control device for a rotating electrical machine according to claim 1, wherein the harmonic current information acquiring section includes a detection value inputting section that uses a detection value of a current flowing through the rotating electrical machine as input and acquires the information related to harmonic currents.

16 The control device for a rotating electrical machine according to claim 15, wherein

the alternating-current voltage applying device is a direct current-to-alternating current converter circuit that selectively connects a terminal of the rotating electrical machine with a positive electrode or a negative electrode of a direct-current voltage source; and

the manipulated variable calculating section performs a process for calculating a manipulated variable based on the information related to harmonic currents in at least an overmodulation range.

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17. The control device for a rotating electrical machine according to claim 16, wherein

the rotating electrical machine includes a rotating shaft mechanically connected to another means for generating torque subjected to electronic control; and

the designated torque value serving as input of the manipulated variable calculating section is a torque value assigned to the rotating electrical machine among torque value respectively assigned to the other means and the rotating electrical machine.

18. A power control unit for a rotating electrical machine, comprising:

an inverter; and

a motor generator electronic control unit for operating the inverter, the motor generator electronic control unit being configured to:

acquire information related to harmonic currents flowing to the rotating electrical machine;

calculate a compensation amount for compensating an amount of loss attributed to the harmonic currents and

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an amount of loss attributed to a fundamental current flowing through the rotating electrical machine by using, as input, the acquired information related to harmonic currents, an electric angular velocity of the rotating electrical machine, and a designated torque value of a controlled variable of the rotating electrical machine or a current amplitude of the rotating electrical machine;

correct the designated torque value of the controlled variable by adding the compensation amount to the designated torque value of the controlled variable;

calculate a manipulated variable to control torque serving as a controlled variable of the rotating electrical machine to the corrected designated torque value of the controlled variable; and

operate an alternating-current voltage applying device that applies an alternating-current voltage to the rotating electrical machine, based on the calculated manipulated variable.

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